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RESEARCH AT THE STANFORD CENTER FOR RADAR ASTRONOMY

Research conducted in whole or in part under NASA Grant no. 377 includes theoretical and experimental radio and radar studies of lunar and planetary ionospheres, atmospheres, and surfaces, and radar studies of the sun and interplanetary medium.

PLANETARY RESEARCH

A report: "The Bistatic Radar-Occultation Method for the Study of Planetary Atmospheres," by G. Fjeldbo and V. R. Eshleman, 1965 summarizes some of the planetary research supported by NsG 377. This paper is also submitted for publication in the JGR. While other aspects of the problem are still being supported by the grant, Stanford's participation in the Mariner C telemetry occultation experiment has now been funded separately under NGR 05-020-065. Measurements of amplitude and phase path will be used for two independent determinations of the refractive index profile of the Martian atmosphere.

A study has been started of possible models for the atmosphere of Mars. This study is necessary in order to estimate the perturbations expected to the telemetry signal, and to interpret the data when they become available. Current estimates show that the telemetry signal is affected both by the troposphere and the ionosphere. These perturbations should provide important new information on scale height and densities both in the troposphere and the ionosphere of Mars.

MAGNETOHYDRODYNAMIC WAVES IN INTERPLANETARY SPACE

Recent spacecraft measurements have brought back highly indicative, though inconclusive, evidence of shock waves in the interplanetary medium. Heretofore, uncertainty existed as to whether shock waves can exist in collision-free plasmas. Additional independent verification of their existence is necessary. It is suggested that bistatic radar can fill this role admirably. In addition to having the ability to detect the presence of the interplanetary shocks, bistatic radar is capable of measuring a number of shock parameters such as compression ratio, speed, etc. To determine the measureable parameters, the effect of a shock wave propagating across the raypath of the transmitted electromagnetic wave must be established. Consequently, propagation characteristics of the radio wave in a stream medium in the presence of a uniform magnetic field have been derived. These results have been used to arrive at methods of measuring particle density and stream velocity without having to neglect the effects of the magnetic field of the medium. The effects of neglectingan isotropic path splitting, ray refraction, and errors arising from the "high frequency" approximation have been analyzed. Initial results show that a large amount of information about the steady shock parameters can be obtained from a small number of actual measurements. Currently, the possibility of using bistatic radar for obtaining additional information concerning the physical structure of collisionless shocks is being investigated.

SOLAR RADAR PROGRAM

During the months of July through September, a total of 127 solar radar runs were made using the 300 kilowatt transmitter near 25 mcs and the 48 element log periodic array. Each run consists of transmitting a cw signal with an effective radiated power of 105 megawatts for the 17 minute round trip time to the sun. In practice the signal is frequency shift keyed between two frequencies separated by 40 kilocycles at 25 mcs in a pseudo random manner. The pseudo random sequence is generated by a shift register and is 127 bits long. When driven by a 4 second clock this produces a 508 second code which is transmitted nearly twice during a run.

A number of minor changes in the transmission and reception control system make the timing and sequencing nearly automatic and allow rapid changes in the radar mode from "sun" to "moon" for other operation. The only major change in operation was the increase of the keyed frequency shift from 16 to 40 kc.

Several modifications were made to the data processing system including the addition of an IBM 1620 for digitizing, quadratic instead of linear detection, and the reduction of range increments from two seconds to one. Use of test runs (a mock signal plus solar noise) demonstrated the system's ability to detect a signal more than 25 db below the noise. This was somewhat better than the earlier system and, therefore, all of the 1963 data were reprocessed. Despite the increased sensitivity no echoes were detected.

The 1964 data have now been completely digitized and are in the final stages of reduction at the present time. One difficulty has been that the 1964 data tapes exhibit a very small, extremely slow fluctuation in output which is stable enough to add up when the runs of a number of days are summed.

It has been shown that the fault is in the radar data recorder and is simple enough to remove from the data with digital filtering techniques. The effect, while displeasing, is not large enough to mask even weak solar echoes when properly filtered. The present data will be re-run through the IBM 7090 when a new program is completed.

Despite an overall improvement in sensitivity and nearly three times more data than 1963, no solar echoes were evident in either the individual or summed computer outputs. When compared with the Lincoln Laboratory results which show that the cross section decreased by a factor of two from 1963 to 1964, this result is not too surprising. There is some argument, however, that the cross section is now on the increase and, for that reason, solar runs are now being contemplated for summer 1965.

Further work on the present data tapes will include elimination of the long term component and a re-summing of all data. A more complex correlation program has been written to combat non-stationary noise while optimizing the remaining details of the processing. It has been used with test runs and does show some improvement over the present program. Further theoretical work is being done to find the best possible method or combination of methods for the extraction of very small signals.

CISLUNAR GAS STUDIES

Analysis of the two frequency lunar radar data is progressing very well. Concentrated efforts during the previous reporting period produced nearly five months of lunar data (operation two hours per day five days per week) which have been completely digitized and stored on magnetic tape. To date, the two effects most completely analyzed are the Faraday polarization which gives a measure of ionospheric electron content, and dispersive Doppler which provides a number for the rate of change of electron content over the entire earth-moon path. Comparison of these two measurements can be used to separate purely ionospheric changes from total path changes and, significantly, a difference in behavior has been found between the daytime and nighttime results.

The daytime results show a post sunrise and pre-sunset effect which is interpreted as a diurnal exchange of ionization between the upper ionosphere and the lower magnetosphere. It is suggested that there is a net upward shift of photo electrons along the magnetic field lines during the morning and a net downward shift in the afternoon. The maximum flow rate of electrons is about 3×10^{12} electrons/m^2/sec and the total change across the boundary can amount to 5×10^{16} electrons/m^2.

The nighttime results show an increase of electron content above the ionosphere in the evening hours as the moon moves toward the antisolar direction and a decrease in the pre-dawn hours when it is moving back toward the sun. It is suggested that the changes are caused first by the increase and then by the decrease of the raypath within the magnetohydrodynamic shock wave boundary as the moon moves in and out of the magnetospheric wake. This interpretation requires a change of about 200 electrons/cc when crossing the shock boundary. Assuming isotropic distribution and an average energy of 2.5 ev the IMP 1 low energy electron flux measurements show a density change of about

150 electrons/cc at the boundary.

During several nights at the end of December, the two radars were used to perform the first measurement of the total integrated electron density between the earth and the moon. The measurement was accomplished by measuring the difference in time delay between the 25- and 50-Mc moon reflected signals to an accuracy of 10 μsec.

The experiment was made possible by the use of FM radar transmissions with time-bandwidth products of 10^5. Both the transmitter and receiver linear-sweep waveforms were fully synthesized from a common frequency standard, and this precise timing, coupled with the strong quasi-specular return from the moon's edge, makes possible the full realization of the radar's range accuracy.

Preliminary analysis of the differential group delay between 25- and 50-Mc echoes during the early morning hours gives an integrated density of 300 ± 20 electrons/cc. The data were taken at a time when the electron content of the earth's ionosphere could account for between 75 and 150 electrons/cc if spread over the entire path. From this it can be seen that an upper limit of about 225 electrons/cc is placed upon the density above the ionosphere.

DATA PROCESSING

During the past year effort has been directed toward developing the data processing capabilities of the Center for Radar Astronomy. These capabilities make use of two computer facilities at Stanford: The Computation Center and the Hybrid Computer Laboratory.

The Stanford Computation Center is run by the Computer Sciences Department and is partially supported by NSF Grant GP-948. It has two large computers, a Burroughs B5000, and an IBM 7090 with an IBM 1401 for in-out buffering. In addition, there is extensive off-line equipment: card punches, duplicators, listers, a sorter, interpreter, and digital plotter. The Computation Center has developed a compiler and an extensive library of subprograms including routines for easy use of the magnetic tape facilities and the digital plotter.

The Hybrid Computer Laboratory is run jointly by the Systems Theory and Radioscience divisions of the Stanford Electrical Engineering Department. It has an IBM 1620 digital computer connected to a six-channel analog-to-digital and digital-to-analog converter, two counters, a card reader and punch, and a digital magnetic tape machine. In addition, the facility has a seven-channel tape recorder, an EAI TR-48 and an EAI 16-31R analog computer. These components all feed through a simple patch panel to allow quick changeover for different data processing requirements.

The Center's use of these facilities has been developed in several ways. Development of the Hybrid Computer Laboratory has been monitored to ensure that it remains efficient for processing radar astronomy data. A programmer has been trained for the IBM 1620 and has written a number of general purpose programs to scale and edit raw data and output the data cards or digital tape. (Since the larger computers are so much faster and therefore less costly for a given computation, the smaller IBM 1620 is used primarily to scale and edit data for the larger machines.) Subprograms have been written to input the edited data to the computers at the Computation Center. At this stage experiments usually require special programs to handle the different types of data. These programs are written by SCRA graduate students, most of whom have learned the compiler languages of the large computers (FORTRAN, ALGOL, or BALGOL) in their course work.

These data processing capabilities have been used extensively during the last year and will play a large role in future experiments. The importance of automatic processing is illustrated by the moon radar experiment. Data from this experiment are processed at a cost of about $60 per day of data, including all computer and operator costs. Before the automatic processing, it required about one man-month per day of data, for a cost of nearly $600. To date, over four months of these data have been digitally processed. Furthermore, in addition to computing and displaying the basic results of the day's run, the computer stores the original data in easily accessible form on digital magnetic tape. These data are then available for extensive study of other moon radar phenomena, such as fading, absorption, depolarization, etc.

In addition to the moon radar experiment the data processing facilities have been used in the solar radar experiment, the auroral backscatter experiment, and the Jupiter storm correlation. Non-SCRA users of these new facilities include workers concerned with Syncom satellite analysis, VLF propagation studies, and, in the near future, the facilities will be used in meteor radar experiments and in Jupiter and solar polarization studies.

PUBLICATIONS

"An Antenna Array for Radar Astronomy Studies in the 20 to 55 Mc Range," by H. T. Howard, Technical Report No. 3, contract NsG-377, Radioscience Laboratory, Stanford University, California, August 1964.

"Radar Astronomy of Solar System Plasmas," by V. R. Eshleman, Scientific Report No. 4, contract NsG-377, Radioscience Laboratory, Stanford University, California, August 1964.

"A model Fokker-Planck equation for a plasma and its solution," by J. P. Dougherty, Physics of Fluids, vol. 7, no. 11, pp. 1788-1799, November 1964.

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"Ground Bistatic Radar Astronomy," by H. T. Howard and W. C. Erickson, J. Geophys. Res., March 1965.

"An Antenna Array for Radar Astronomy Studies in the 20 to 55 Mc Range," by H. T. Howard, IEEE Transactions on Antennas and Propagation, May 1965.

"The Bistatic Radar-Occultation Method for the study of Planetary Atmospheres," by G. Fjeldbo and V. R. Eshleman, J. Geophys. Res.

PAPERS PRESENTED

"Man in Extreme Environment," by B. B. Lusignan, ONR Space Science Seminar on Radar Astronomy, September 1964.

"Radar Astronomy of Solar System Plasmas," by V. R. Eshleman, contribution to Proc. of NATO Advanced Institute for Radio Astronomy, Cape Sounion, Greece, August 1964.

BUDGET

The total amount of this research grant for the three year period from 1 January 1963 to 31 December 1965 is $455,044.00. The balance remaining at the end of this reporting period is $123,139.00.